9th South African Conference on Computational and Applied Mechanics
Somerset West
14 – 16 January 2014

Effect of HHO on Four Stroke Petrol Engine Performance

Daniel M. Madyira[1], Wayne G. Harding[2]

[1,2]Department of Mechanical Engineering Science, Faculty of Engineering & the Built Environment, University of Johannesburg, Auckland Park 2006, Johannesburg

dmadyira@uj.ac.za

Abstract: Contemporary research into alternative sources of energy for transportation focuses mainly on electric/battery, hybrid and hydrogen powered vehicles. Such focus assumes that the current technology has to be discarded and cannot be improved. However, it is possible to introduce interim technology to alleviate the current challenges arising from continued reliance on fossil fuels. Such challenges include increased greenhouse gas (GHG) emissions with consequent global warming and climate change impacts. The purpose of this research work is to determine if the partial inclusion of hydrogen gas (HHO) in a petrol fuelled spark ignition (SI) internal combustion (IC) engine would improve engine performance. If this is possible, old SI technology can be modified to reduce GHG emissions and improve utilisation of fossil fuels which are expected to dominate the transport energy source for at least the next half century. An HHO generator was designed, constructed and mounted in the engine compartment of a 1989 Ford Laser vehicle. This system allowed partial inclusion of HHO gas on demand into the combustion process through the air supply stream. Detailed and comprehensive experimental investigations were conducted for engine speeds ranging from 1000 to 3500 rpm while parameters such as the power output, exhaust gas emissions and fuel consumption were monitored. Results obtained indicated a decrease in hydrocarbon emissions and an increase in power output with an increase in the HHO gas for certain engine operating conditions. However, performance improvement cannot be claimed for all operating conditions, especially under higher loads where the engine ran with a rich fuel mixture. Hence, further work is required, through HHO generator refinement alongside better engine management, to improve the experimental performance and hence further understanding of this technology.

Keywords: Brake Power, Internal Combustion Engine, Hydrogen Gas, HHO Generator, Spark Ignition, Specific Fuel Consumption.

INTRODUCTION

Fossil fuels currently constitute 82% of the global total primary energy sources [1] and oil makes 31.5 % of this. Of the global oil production, 62.2% is consumed by the transport sector [2]. Thus, the automotive industry is the largest consumer of fossil oil. Studies have also shown that the demand for oil and gas is rising exponentially and indications are that fossil fuels will not outlast the century if current habits are not curtailed [3]. Hence, in response to the growing fuel prices and the increasing pressures for a cleaner "greener" society, the automotive industry has made efforts to reduce emissions and increase fuel efficiency [4]. These efforts have primarily focussed on emissions reductions using catalytic converters, reducing vehicle weight, using alternative structural materials, improving engine management and fuel supply systems, incorporating the stop - start technology and introducing alternative sources of energy such as hydrogen fuel cells, biofuels and others. Governments and municipalities have also made efforts through the development and implementation of legislation [5]. For example, the Euro 6 Code limits tailpipe emissions for vehicles with less than 8 seats to 1000 mg/km of carbon monoxide, 100 mg/km of total hydrocarbons and 60 mg/km of nitrogen oxides [6]. This applies to positive ignition engines introduced into the European Union from 1 January 2014.

As regulations become more restrictive and global fossil fuel prices increase, the search for more sustainable sources of transportation fuels becomes more urgent. The current research into alternative energy sources for motor vehicles is mainly concentrated around electric/battery powered cars, hydrogen fuel cells, solar and hydrogen powered cars. These technologies, as promising as they may be, will not completely replace the fossil fuelled internal combustion engine within the next few decades. One of the major hindrances will be the lack of supporting infrastructure such as fuel supply and distribution centres. There is therefore potential for a bridging or interim technology that can be incorporated into existing technology using the existing infrastructure, which can lead to greener use of available fossil resources. One such option is the introduction of hydrogen gas into the combustion process of an IC engine.

Hydrogen gas is an example of a renewable energy source that can be used to partially supplement diesel or petrol fuel by enriching supply air. Advantages of introducing hydrogen gas include higher net heating value and diffusivity of hydrogen in air when compared to fossil fuels. This means that including it in the combustion process can lead to a more complete combustion of the fuel air mix as reported by Yadav et al [7]. A more complete combustion can result in the reduction of harmful exhaust emissions such as hydrocarbons (HCs), nitrogen oxides (NOx) and carbon monoxide (CO). In addition, better diffusivity produces a much faster flame velocity (on the order of 10x) that can lead to a better acceleration and torque output from the engine [8].

Musmar and Al-Rousan [9] conducted detailed research on the performance of a single cylinder Honda G 200 engine using air enriched with HHO gas. The HHO generator used was box shaped, with electrodes made of stainless steel grade 316-L, electrolysing water. The water was enhanced using sodium bicarbonate. The engine speed was varied from 1000 rpm to 2300 rpm. This work demonstrated the feasibility of introducing an HHO generator into the engine compartment as the generator was about the size of a standard 12V car battery. In addition introduction of HHO resulted in 54% reduction in NOx and 20% reduction in CO. It was also noted that HHO concentration varied with engine speed. This could have been a result of no control on electric current fed to the generator. No information is given on the performance of the HHO generator used.

In more recent work, Leelakrishnan and Suriyan [10] investigated the effects of HHO gas enriched air on the performance of a single cylinder, four stroke, 5.4 kW SI petrol engine. Enriched air was supplied to the engine through a passage between the air filter and the carburettor. Results reported indicate 5% improvement in brake power, 7% improvement in thermal efficiency, 6% reduction in fuel consumption, 88% reduction in unburnt hydrocarbons (HC), 94% reduction in CO and 58% reduction in NOx. These values were reported at full load. However, no information was given on the rate of production of the HHO gas or whether there was variation in gas production during the test. Furthermore, the engine used is not representative of the current technology on the road.

This project investigates the engine performance from partially including hydrogen gas (also known as brown's gas or HHO gas) into the combustion process of a conventional spark-ignition engine. In the authors' knowledge, no work has been reported in literature on existing engines already in service. A device, stored in the engine compartment, will produce the HHO gas through electrolysis of distilled water and an added electrolyte (sodium bicarbonate is a good option). Similar work done by Al-Rousan has shown that this can increase fuel efficiency, engine torque and reduce harmful exhaust emissions [11]. However, in this investigation, Al-Rousan made use of a constant HHO gas output rather than metering out the gas according to the air-fuel mixture requirements of the engine. The proposed device will monitor the volume flow rate of air into the engine and produce HHO gas accordingly by controlling the supply current to the HHO generator thus helping to maintain a more consistent and predictable air-fuel mixture.

One of the challenges of using hydrogen gas in automotive applications is storage. Large tanks would be required if HHO was not generated on-board. Therefore, the generation of hydrogen gas on-board the vehicle can reduce the risks of having to store this highly explosive gas. However, the generation of hydrogen does come at a cost. It will introduce a load on the vehicle's battery and alternator, thus sapping engine power. It is anticipated that the introduction of HHO gas into the combustion process will lead to better combustion, increased engine power and reduced emissions as reported in reviewed literature. This will have the effect of improving the cleanness of conventional fuels which continue to dominate the energy mix in the transport sector.

EXPERIMENTAL PROGRAMME

Experiment Design

The schematic of the overall design of the experimental setup is shown in Figure 1. The main difference between this design and those reported in the literature is the implementation of the control system shown in dotted lines.

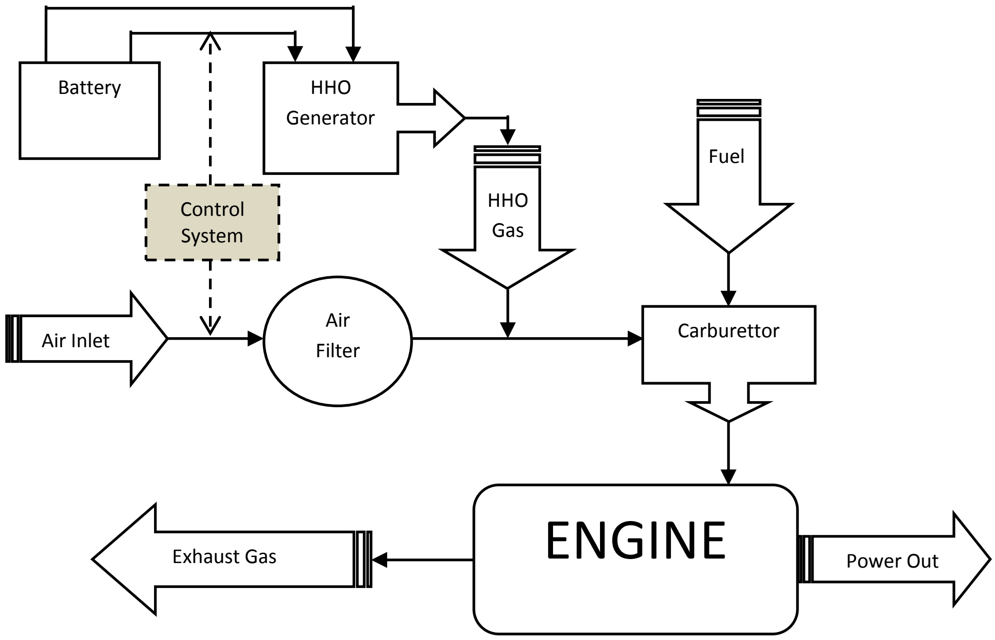
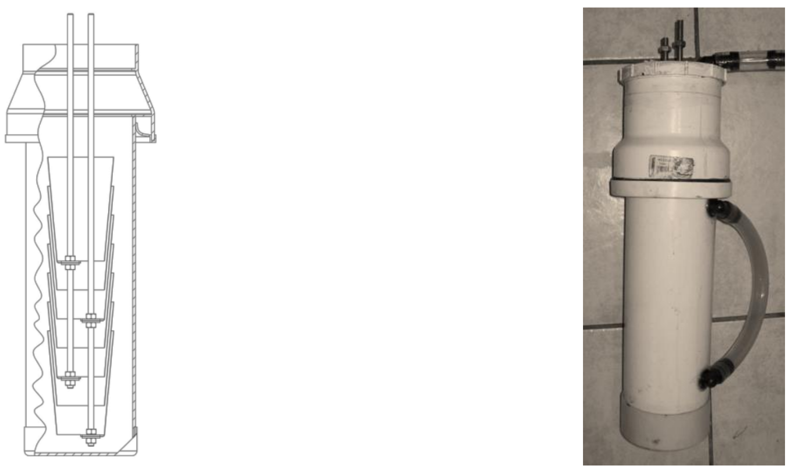


Figure 1: Schematic of the experimental design showing implemented control system

Hydrogen Generator

The HHO generator container was constructed from 110 mm PVC pipe and has a capacity of 3 litres. A standard 110 mm PVC end cap was used to seal the bottom. A push-over/compression fitting cover was used as the lid. This ensures that no excessive pressures can build up within the cell. Modified stainless steel tumblers were used as the electrodes. There are 7 electrodes, configured in alternate form (+N-N+N-). In this representation (+) represents the positive electrode, (N) represents neutral and (-) represents the negative electrode. The gap between adjacent tumblers was limited to 3 mm using spacers. In addition, transparent tubing was mounted to the wall of the container to provide visual indication of electrolyte level. Figure 2 shows a schematic and picture of the HHO generator.



(a) (b)

Figure 2: Hydrogen generator (a) Internal design schematic (b) Picture showing transparent tube

Vehicle Description

A 1.5 litre four cylinder, spark ignition engine on a 1989 Ford Laser vehicle was used for the investigation. This car is currently operating on the road and hence gives representative technology performance. Slight modifications were made to accommodate test equipment and procedures. A more detailed specification of the car is given in Table 1.

Table 1: 1989 Ford Laser specifications [12]

Parameter	Value
Engine	1500 GLS
Capacity (m^3)	1490
Bore × Stroke (mm)	77 × 69.6
Compression ratio	9.0:1
Net power at 5500 rpm (kW)	56.6
Net torque at 3000 rpm (N-m)	117
Engine idle speed (rpm)	850 ± 50

Experimental Procedure

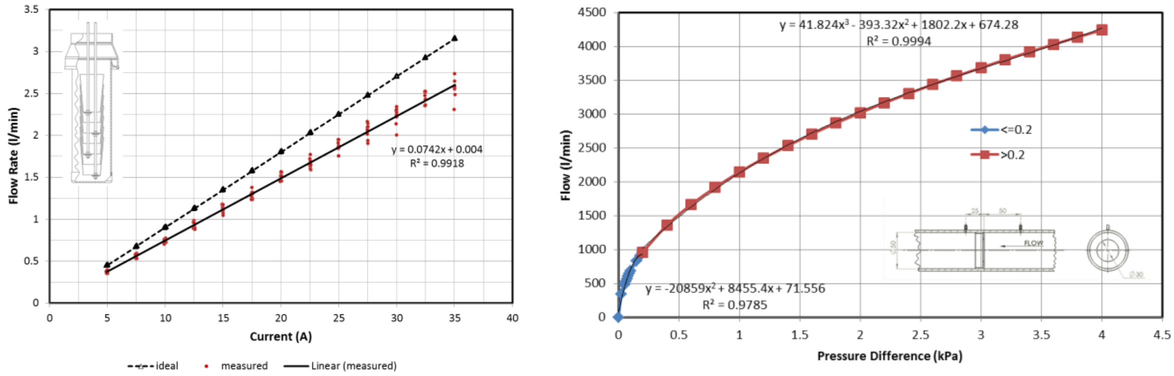
The vehicle power was measured using a road dynamometer. The power was specified as a fraction of the maximum dynamometer load. Exhaust gas emissions were measured using Nextech NGA 6000 automotive gas analyser. Exhaust gas and ambient temperatures were monitored using K-type thermocouples. The thermocouple used to measure the exhaust gas temperature was inserted into the exhaust manifold ensuring that it did not touch the exhaust side walls. A gravity fed fuel supply system with an in-house made graduated fuel reservoir was used during the test. Fuel consumption was read off the graduated reservoir over a specified time span. A special orifice plate, that was also developed in-house, was used to monitor the air flow rate. This was implemented using an Arduino Uno prototyping platform. The same unit was also used for data logging and for controlling power supply to the hydrogen generator. The Pulse Width Modulation (PWM) function on the Arduino was used as the input signal to change the duty cycle for the supply to the generator. The change in duty cycle resulted in a change of current supplied to the HHO generator.

The air-fuel ratio of the engine was calibrated at 30% load to a value of 14.7. This was achieved by adjusting the carburettor float and monitored through exhaust gas composition. The HHO gas generator was also monitored under no load and the relationship between the current and gas yield was determined. This was then implemented in the generator control system during the experiments. Baseline performance of the engine was determined prior to full testing. Tests were conducted for speeds of 1000, 2000, 2500, 3000 and 3500 rpm. For each speed, the load was varied in steps of 10 from 0 to 30 %.

RESULTS AND DISCUSSION

System Calibration

The control system for the HHO generator was run using the response functions shown in Figure 3. Figure 3(a) shows the measured variation of the HHO gas output as a function of input current. A comparison is also made with the expected theoretical response according to Faraday's law. However, the obtained gas yield was consistently below the theoretical expectation. Figure 3(b) shows the monitored variation of air flow rate across the orifice plate as a function of pressure drop. Therefore, during the tests, the measured pressure drop across the orifice plate gave the air flow rate which gave the required current (Figure 3(a)) to maintain the target air-fuel ratio. This procedure was implemented in the Arduino Uno prototyping function and was the basis for the control system used to run the HHO generator. Note that the pressure function was divided into two; one for pressure difference less that 0.2 kPa and one for a higher value.

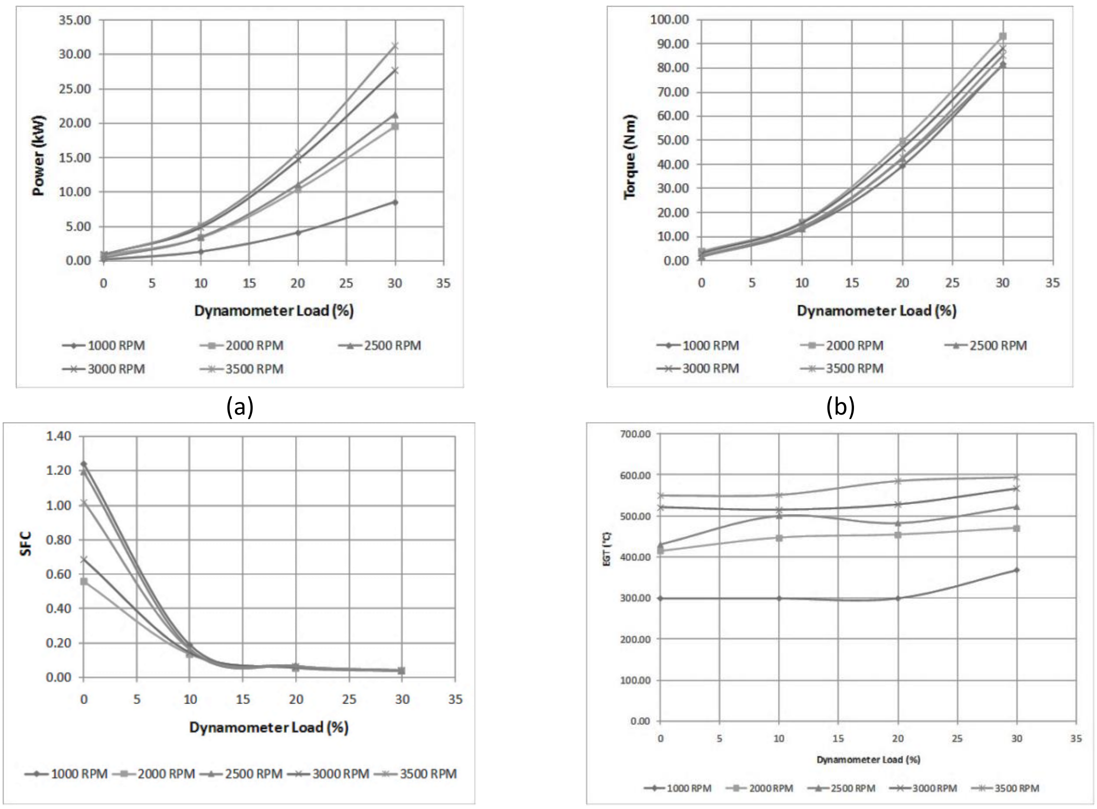


(a) (b)

Figure 3: Calibration functions (a) HHO generator (b) Orifice plate

Baseline Results

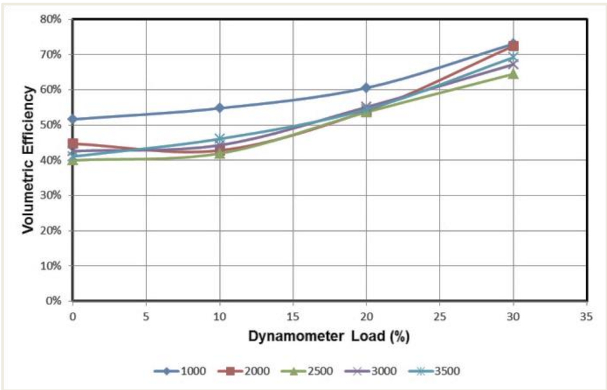
Baseline results give the performance of the engine under experimental conditions but without HHO enrichments. Experimental results with HHO enrichment will then indicate percentage deviation from the baseline results. Figure 4 shows the key baseline results for the engine used.

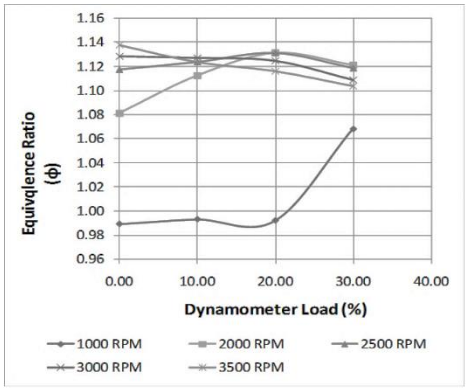


(c) (d)

Figure 4: Baseline results (a) Power (b) Torque (c) Specific fuel consumption (d) Exhaust temperatures

Figure 4(a) shows the baseline variation of power with dynamometer load for the selected test speeds. As expected, for any given speed, the power increases with load. The same behaviour is expected for torque as higher torque is required to maintain the same rotational speed as the load is increased (Figure 4(b)). However, evaluating the cost of the increase in that power is important. Hence, Figure 4(c) shows the variation of specific fuel consumption (SFC) with load for the same speed range. The SFC decreases with increase in load and the curves converge to the same value close to 15% load setting on the dynamometer. This indicates the engine's optimum operating condition. Figure 4(c) shows that the exhaust gas temperature increased from 300°C at 1000 rpm to 600°C at 3500 rpm. This is in line with the observed increase in power. Figure 5 shows the volumetric efficiency and the equivalence ratio. The volumetric efficiency improves with load but decreases with the running speed (Figure 5(a)). Equivalence ratio on the other hand increases dramatically with speed as shown in Figure 5(b). The ideal value of equivalence ratio is 1 for complete combustion. Figure 5(b) shows that at 1000 rpm the engine is running lean while at elevated rpm it runs rich. This is significant in judging the impact of introducing HHO gas.



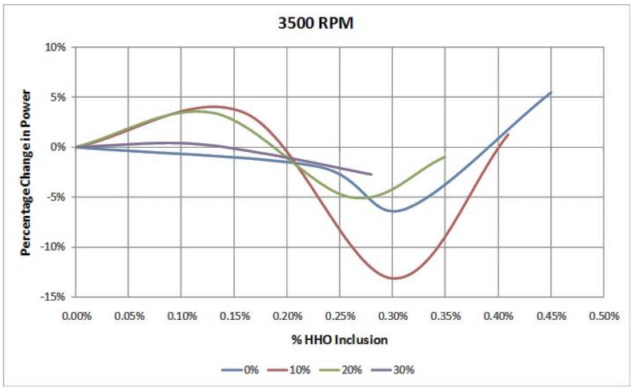


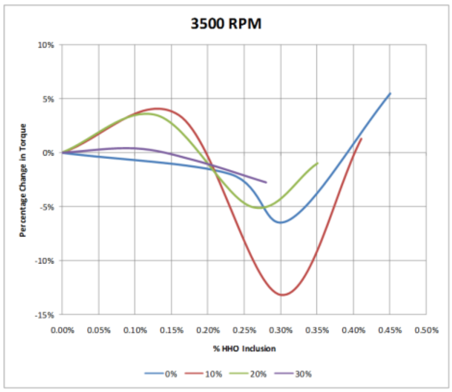
(a) (b)

Figure 5: (a) Volumetric Efficiency (b) Equivalence ratio

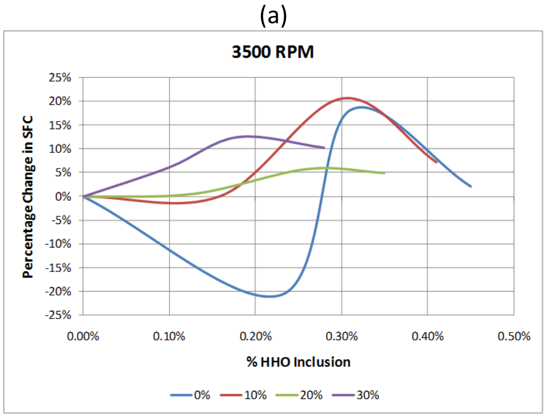
Effect of HHO on Engine Performance

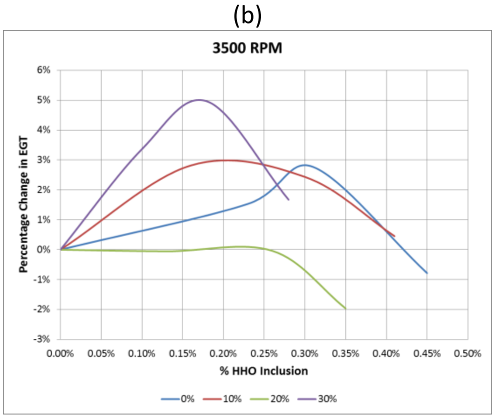
HHO was introduced for volumetric ratios up to 0.45%. This was done for each chosen speed and for each dynamometer load. As a result, a large amount of data was collected. Only representative results can be presented. Typical results for a running speed of 3500 rpm are given in Figure 6. Figure 6(a) presents the percentage change in power from the baseline results caused by the introduction of HHO for various dynamo loads while Figures 6(b), 6(c) and 6(d) present torque, SFC and EGT for the same test parameters.





(a) (b)



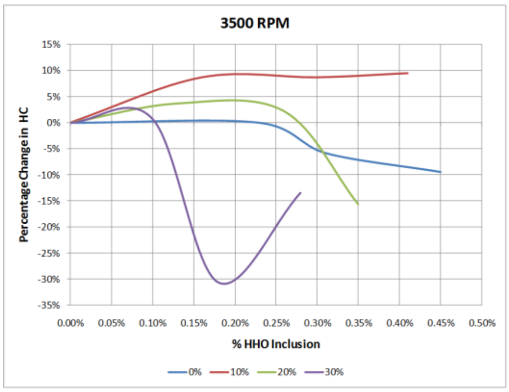


(c) (d)

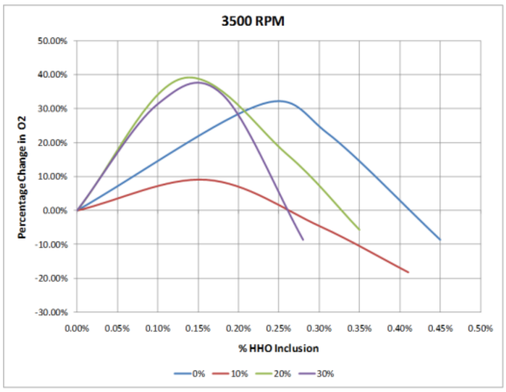
Figure 6: Effect of HHO at 3500 rpm (a) Power (b) Torque (c) Specific Fuel Consumption (d) Exhaust Gas Temperature

Figure 6(a) indicates that an increase in power can be achieved with the introduction of the hydrogen gas. There is more than 4% increase observed for a dynamometer load of 10% at an HHO inclusion of 0.125%. However, the gain is quickly lost as HHO percentage increases. This reinforces the hypothesis that only a small percentage of hydrogen gas is required to improve combustion properties. Figure 6(b) portrays similar behaviour for torque. The fluctuations in the results reveal the sensitive nature of the combustion with the inclusion of hydrogen. These fluctuations can also be attributed to the switching of the alternator. The relationship of specific fuel consumption and the addition of HHO is given in Figure 6(c). It can be seen that the SFC is more than 20% lower under 0% load conditions at 0.2% HHO inclusion. However this reduction is not observed for all the load conditions. A lower SFC is preferred as it means less fuel is required for the same amount of power output. Thus these results are driven by two parameters, power and fuel consumption. Improved power output and improved fuel efficiency can be attributed to increased combustion efficiency. Figure 6(d) shows an increase in exhaust gas temperatures with increase in HHO. This is in line with the expected increase in combustion efficiency for the lower HHO percentages.

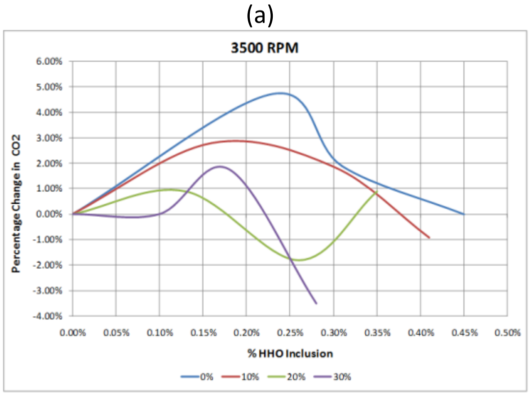
Changes in the emissions were also monitored as a function of HHO percentage and dynamometer load for various engine speeds. Representative data for 3500 rpm is given in Figure 7.



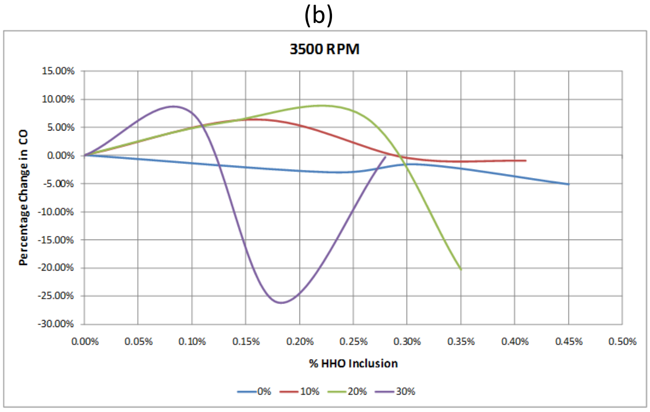
(a)



(b)



(c)



(d)

Figure 7: Effect of HHO on emissions (a) Hydrocarbons (b) Oxygen (c) Carbon dioxide (d) Carbon monoxide

Figure 7(a) does not show a significant reduction in HC as a result of introducing HHO. However, in other cases such as the test conducted at 2000 rpm, there is a clear reduction with HHO percentage increase. Therefore on average the introduction of HHO led to a decrease in the amount of HC in the exhaust gases. This is attributable to a more complete combustion. In general, an increase in oxygen was observed as shown in Figure 7(b). At 30% load, an increase of 30% was observed. This increase can partly be explained by the additional oxygen in HHO. Carbon dioxide is a by-product of the combustion of hydrocarbon. Thus, increased carbon dioxide confirms improvement in combustion as shown in Figure 7(c). This was also observed under other test speeds and loads. Carbon monoxide, on the other hand, represents incomplete combustions. Figure 7(d) shows no major change in carbon monoxide concentration and this was confirmed by tests under different speeds. Results for 1000 rpm are given in Figure 8 for comparison.

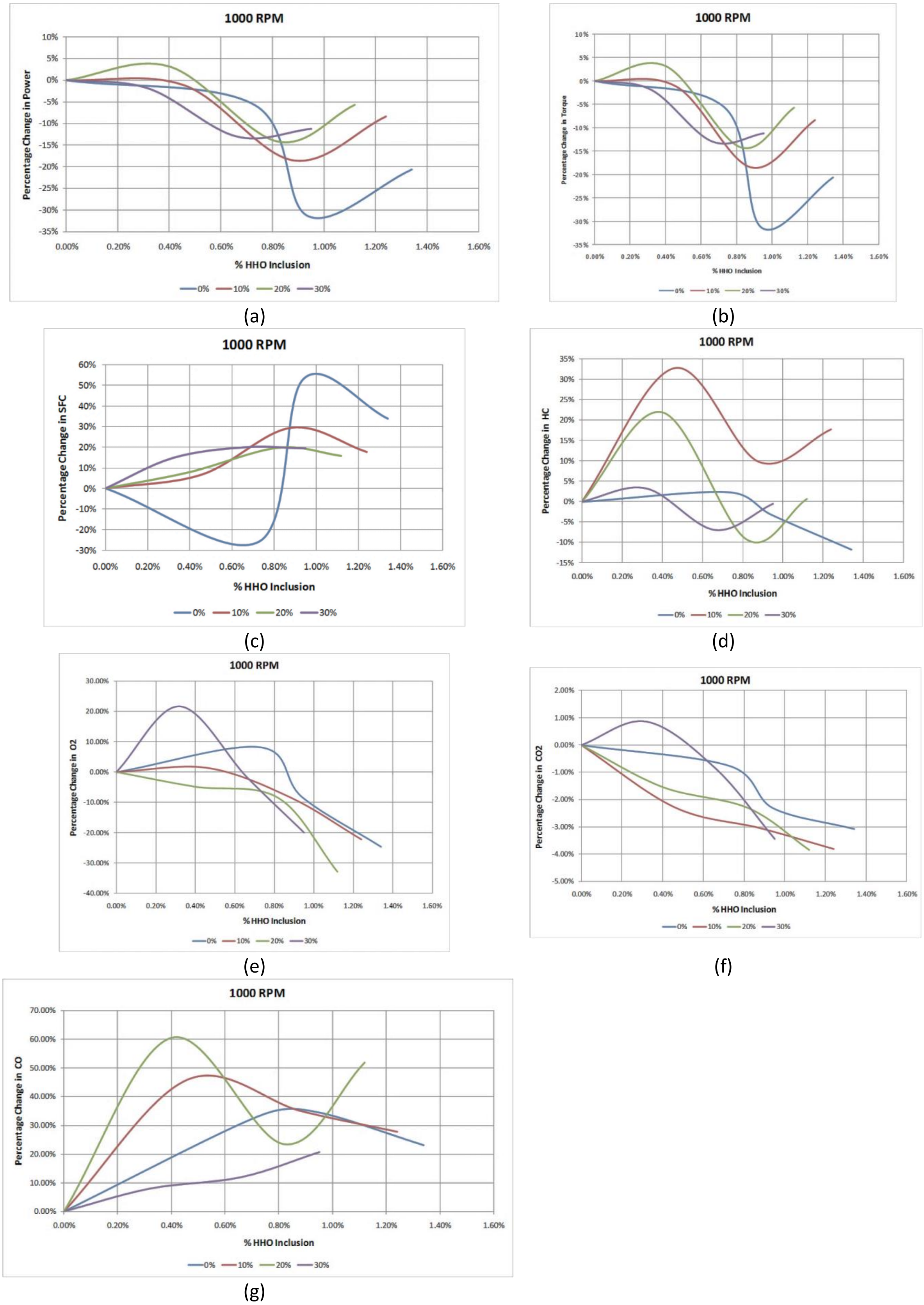


Figure 8: Response at 1000 rpm; (a) Power (b) Torque (c) SFC (d) HC (e) O2 (f) CO2 (g) CO

CONCLUSIONS

In this study, an electrolytic cell was constructed and installed into the engine compartment of a 1989 Ford Laser vehicle that is currently in operation. The cell produced HHO gas that was introduced into the intake manifold of the engine up to a maximum of 0.45% by volume. The vehicle was put on a dynamometer and tested under varying load conditions and speeds. These tests were conducted in order to determine the load performance of the car as a result of the introduced HHO for engine speeds of 1000, 2000, 2500, 3000 and 3500 rpm. Dynamometer load was varied from 0 up to 30% of full load. The results obtained led to the following conclusions:

- The baseline measurements, for the engine in stock condition, provided curves that conformed to the expected behaviour
- Introduction of HHO led to increased power and torque
- The engine tended to run richer under higher loads
- There was a significant reduction of unburned hydrocarbons as a result of the increase in HHO inclusion
- Introduction of HHO led to improved combustion particularly at low loads

Although an increase in power and a reduction in harmful exhaust emissions were observed as a result of addition HHO which was quite promising, however amongst other load conditions and engine speeds, the results contradict this finding. Thus, further research into this technology would be recommended. There is need for further HHO generator refinement and development, alongside use of more modern engine management and control.

ACKNOWLEDGEMENTS

This research work was partly funded by the University of Johannesburg.

REFERENCES

[1] World Energy Council (WEC), "World energy resources: 2013 survey," London, 2013.

[2] International Energy Agency (IEA), "2013 Key world energy statistics," IEA, 2013.

[3] R. R. Singhanai, B. Parameswaran, and A. Pandey, "Plant-based biofuels: An introduction," in *Handbook of plant based biofuels*.: CRC Press, 2009, ch. 1, pp. 3-12.

[4] A. Stone and K. Bennett, "A bulk model of emissions from South African diesel commercial vehicles," Energy Research Institute (ERI), University of Cape Town, Cape Town, 2002.

[5] Y. Scorgie, H. Annegarn, and L. Randell, "Air quality management plan for the City of Johannesburg," Johannesburg, Air Quality Management Plan MTX/03/JHB-01d 2003.

[6] European Union (EU), Euro 5 and 6 Regulation, 2008, (EC) No 715/2007.

[7] M. S. Yadav, S. M. Sawant, and H. V. Chavan, "Investigations on generation methods for oxy-hydrogen gas, its blending with cenventional fuels and effect on the performance of internal combustion engine," *Journal of Mechanical Engineering Reserach*, vol. 3, no. 9, pp. 325-332, September 2011.

[8] J. Wall, "Effect of Brown's gas enriched hydrocarbon combustion on engine emissions and performance," University of Idaho, Idaho, 2010.

[9] S. A. Musmar and A. A. Al-Rousan, "Effect of HHO gas on combustion emissions in gasoline engines,"

journal of Fuel and Energy, vol. 90, pp. 3066-3070, 2011.

[10] E. Leelakrishnan and H. Suriyan, "Performance and emmision chracteristics of Brown's gas enriched air in spark ignition engine," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 2, no. 2, pp. 393-404, February 2013.

[11] A. Al-Rousan, "Reduction of fuel consumption in gasoline engines by introducing HHO gas into intake manifold," *International Journal of Hydrogen*, vol. 35, pp. 12930-12935, August 2003.

[12] Ford Motor COmpany, Laser and Meteor Owner's Manual, 1989, South Africa.